Aura to Exit the A-Train?

Aura Extended Mission Operations Concept

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Background

- The Aura Project Science Office (PSO), in conjunction with ESMO, instrument Principle Investigators and operations teams, have been assessing the feasibility of Aura leaving the A-Train in 2021 as a means of lengthening mission life by conserving fuel.

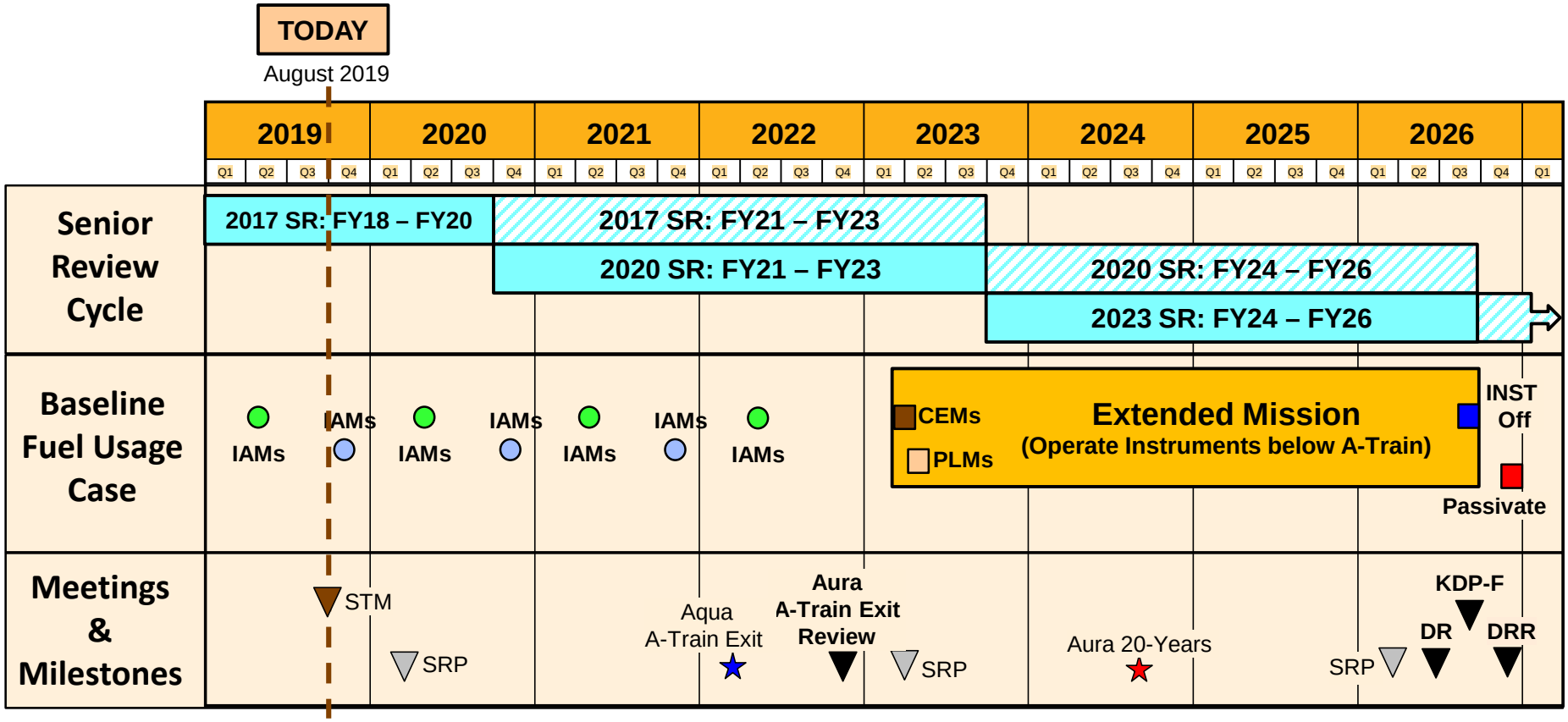
- They weighed the likely impact of leaving on the instrument's ability to maintain science-quality and trend-quality long-term data records, the highest priority of the Aura Mission.

- An important consideration is that MLS collects unique data for several important stratospheric constituents and there is no follow-on mission planned for an instrument with similar capabilities as MLS.

Introduction

- After careful consideration, all parties recommend that the satellite **remain in the A-Train until 2023**
- This will provide the best opportunity for collecting high quality data for the longest duration **(~19 years in the A-Train + ~2-3 years at lower drifting orbit**)
- In advance of any constellation safety concerns and subsequent fuel limitations, the satellite would exit the A-Train constellation and lower perigee to meet the agency 25-year reentry requirement
- After constellation exit and perigee lowering maneuvers, the goal would be to leave the instruments on and continue to collect Science-quality data while lower and drifting, though careful data processing would be required
- Depending on the health of the satellite and the ability to maintain safe operations, the goal will be to maintain operations past 2025 and commence with instrument and mission decommissioning activities when NASA Headquarters deems necessary

Aura Extended Mission Timeline



- **STM** – Aura Science Team Meeting (2019)
- **SRP** – Senior Review Proposal
- Senior Review Funding (Approved)
- Senior Review Funding (Preliminary Guideline)
- **IAMs** – Spring Inclination Adjust Maneuvers
- **IAMs** – Fall Inclination Adjust Maneuvers
- **CEMs** – Constellation Exit Maneuvers
- **PLMs** – Perigee Lowering Maneuvers
- **INST Off** – Power down instruments
- **Passivate** – Spacecraft bus passivation
- A-Train Exit Review (~late 2022)
- **DR** – Decommissioning Review
- **KDP-F** – HQ Key Decision Point to proceed with Phase F
- **DRR** – Disposal Readiness Review

Considerations

Exiting the A-train and altering the operational orbit has several important factors to consider:

<u>Science Considerations</u> –

- Maintaining long-term, science quality data
- Continuing science synergy with other satellites

<u>Spacecraft Considerations</u> –

- Requires a retrograde maneuver capability for Constellation Exit Maneuvers (CEMs) and Perigee Lowering Maneuvers (PLMs)
- Requires ability to maintain operations at lower altitude, with increasing beta angle and drifting Mean Local Time (MLT)
- Power generation and thermal profiles will change as the orbit and beta angle shifts

Considerations

Instrument Considerations –

- During the CEMs and PLMs, the instruments will need to:
  - Identify safe instrument configurations for retrograde maneuvers
  - Examine if there will be any thermal, sun exposure, or contamination concerns

- In order to operate at the new lower orbit, the instruments will need to:
  - Determine if new thermal and sun exposure conditions will pose any concerns
  - Develop new operational products and procedures (i.e., calibration sequences)

- Microwave Limb Sounder (MLS) is not constrained to maintain a particular beta angle or MLT for lighting conditions
  - Careful analysis of the data will be required to maintain science-quality, trend-quality data for MLS, but it is feasible

- Ozone Monitoring Instrument (OMI) is constrained currently to maintain particular beta angle (18.3 deg. – 31.2 deg) for instrument calibration

Spacecraft Limitations

The main Spacecraft Life Limiting Items include:

<u>Fuel Limitations</u> –

- With baseline fuel usage plan, predictions show fuel will reach a limit in **2023**
- With alternate fuel usage plan being considered, benefits have been weighed against impacts towards science and bus subsystems in new orbit profile
  - Implications on power generation and thermal constraints with new beta angle

<u>Power Limitations</u> –

- **Solar Array Power Generation**
  - With current pace of solar string degradation and current spacecraft load, predictions show power margins will start to be a concern in **~2025**
- **Battery Power Storage**
  - No lost battery cells at this point, predictions have shown that the capacity of the cells will be able to support the max depth-of-discharge limit until **~2029**
- Spacecraft load management schemes could be altered to reduce the required power necessary

Aura Fuel Usage Cases

There have been two cases under consideration for fuel usage:

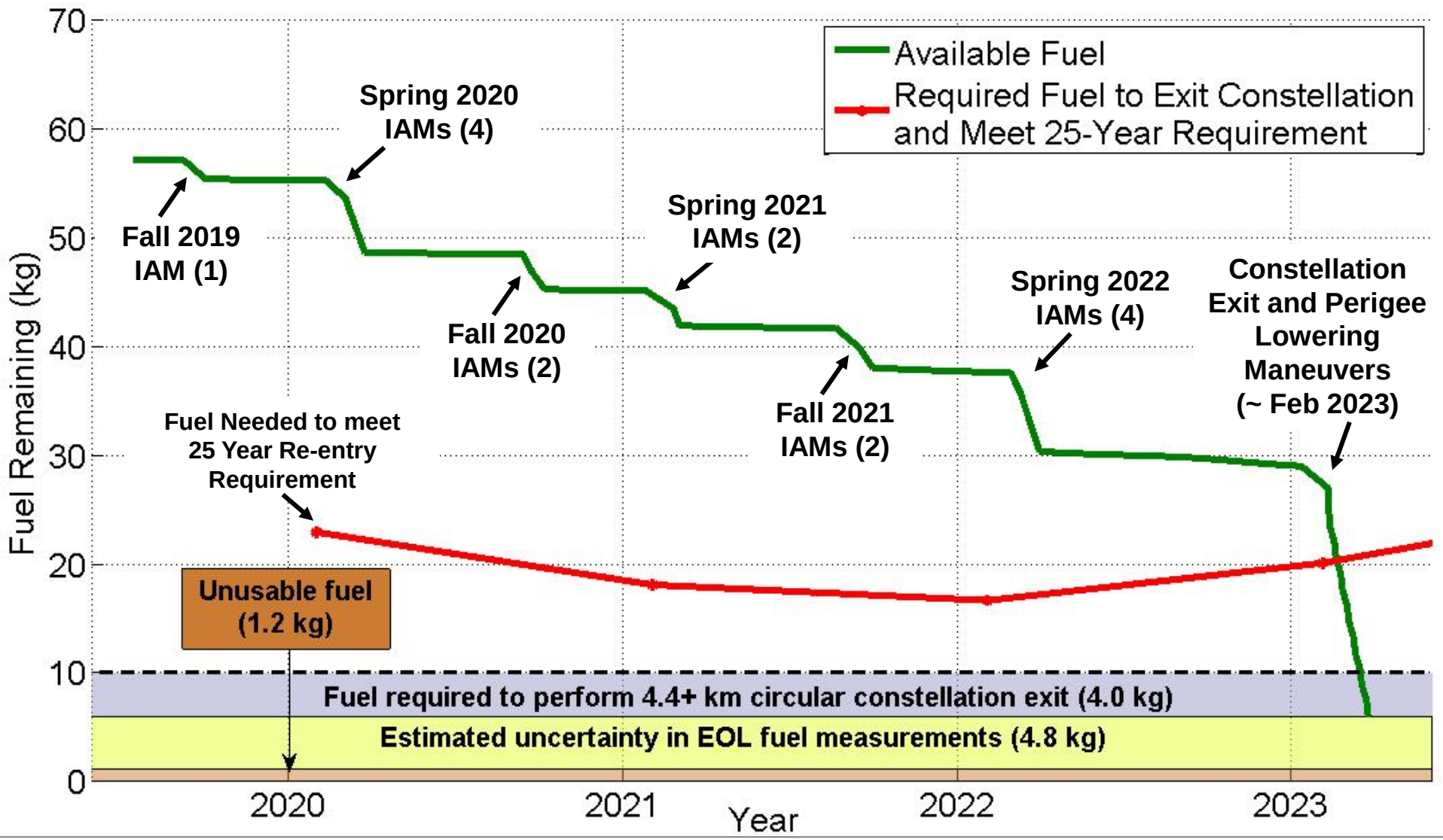
<u>Baseline Fuel Usage Case</u> -

- Maintain MLT and WRS-2 Ground Track requirements until the DAS 25-year re-entry fuel limit is reached in **~2023**
  - Perform Inclination Adjust Maneuvers (IAMs) to maintain Mean Local Time (MLT)
  - Perform Drag Make-up Maneuvers (DMUs) to maintain Ground Track Error (GTE)

<u>Alternate Fuel Usage Case</u> (i.e., Early Exit from the A-Train) -

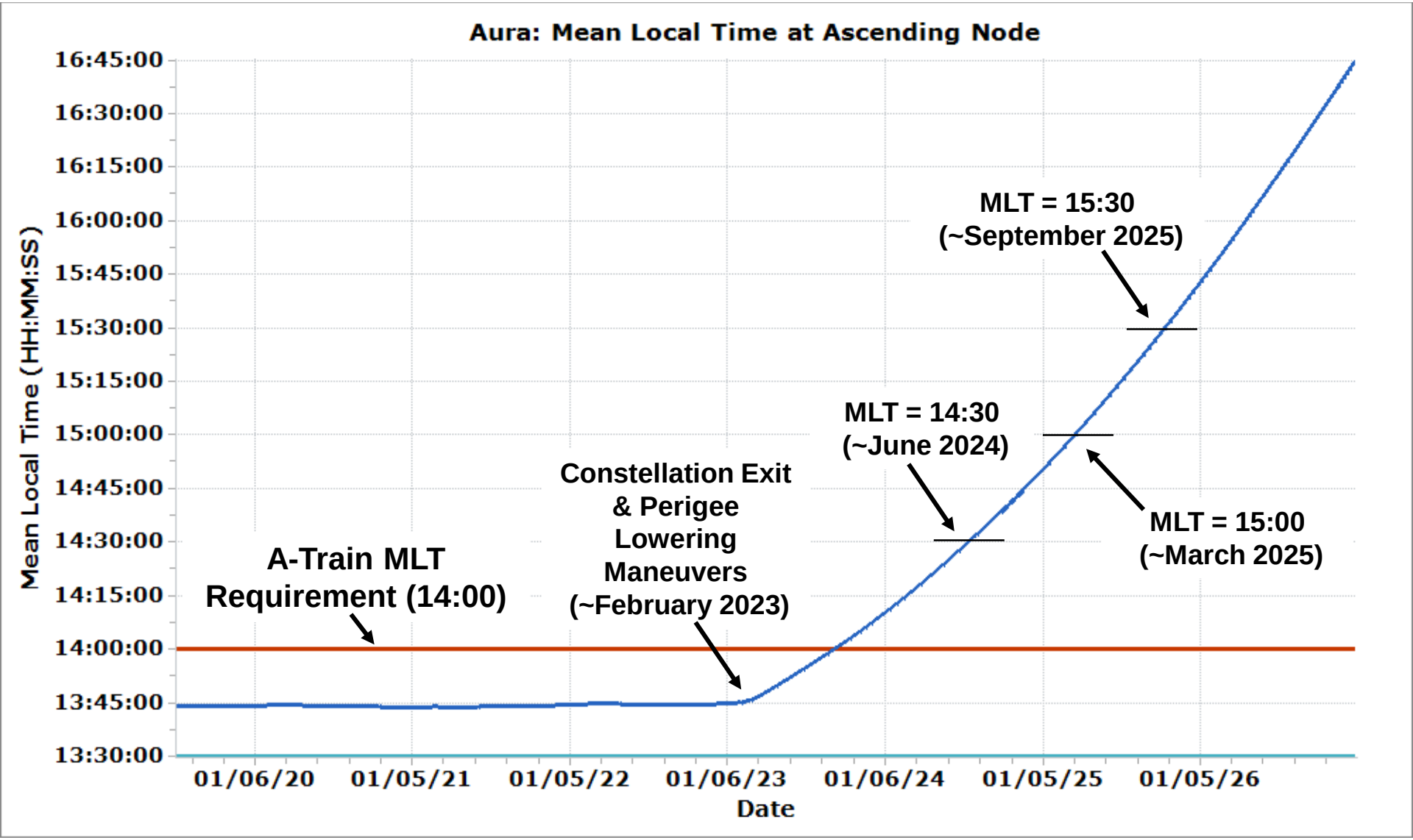
- Once OMI and TROPOMI have a minimum of 2 years of overlap, fuel saving schemes may be a consideration – **after Spring 2020**
  - Perform full IAM Series in 2019 & 2020, stop annual IAMs after 2020
  - Exit A-Train after Spring 2021 (lower 4.4 km in SMA)
  - Allow MLT and Solar Beta Angle to drift
  - Perform periodic DMUs to maintain ground track and frozen orbit

Baseline Fuel Usage Case



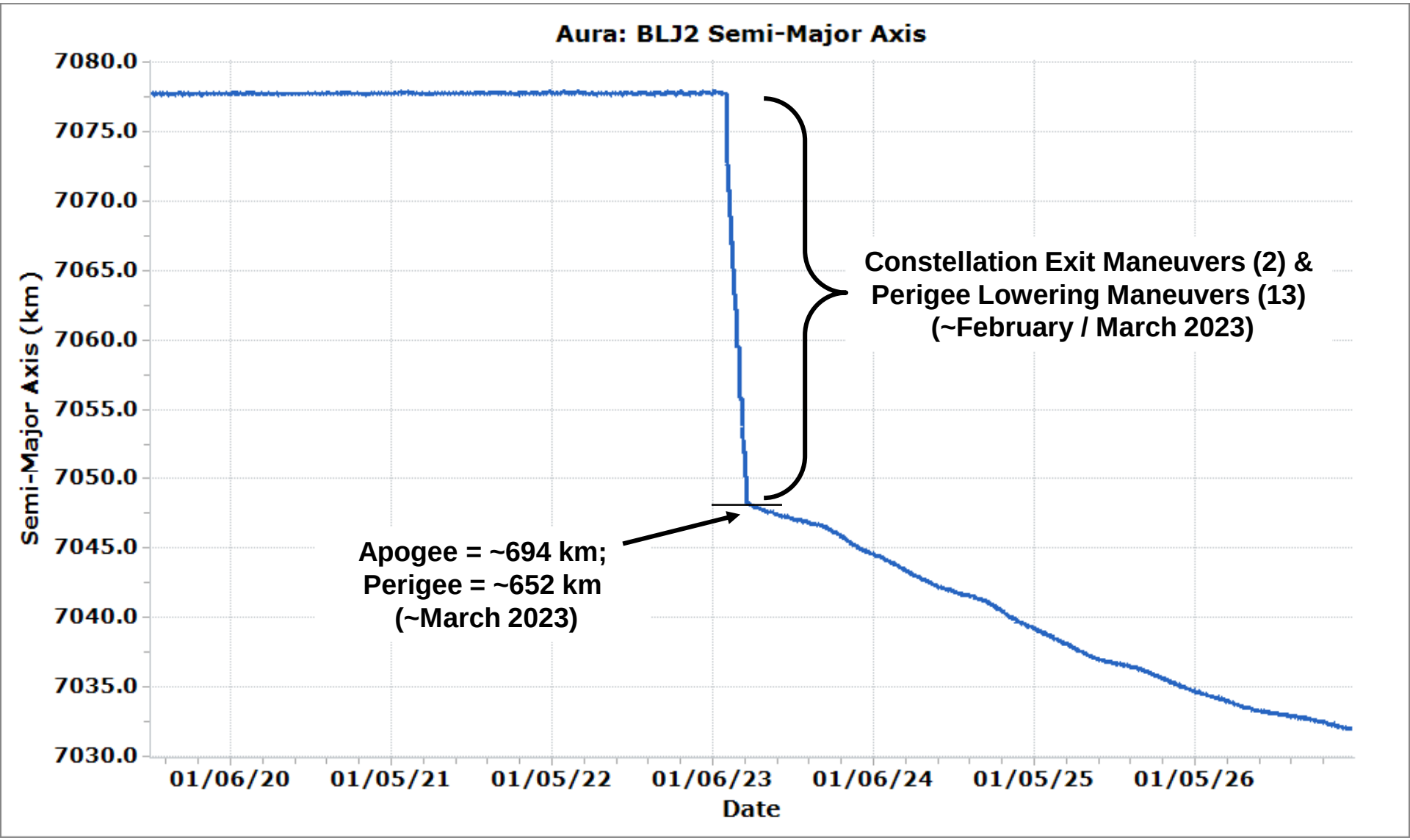
Aura DAS End of Life Predictions
(Analysis Updated August 2019)

Mean Local Time (MLT) Drift



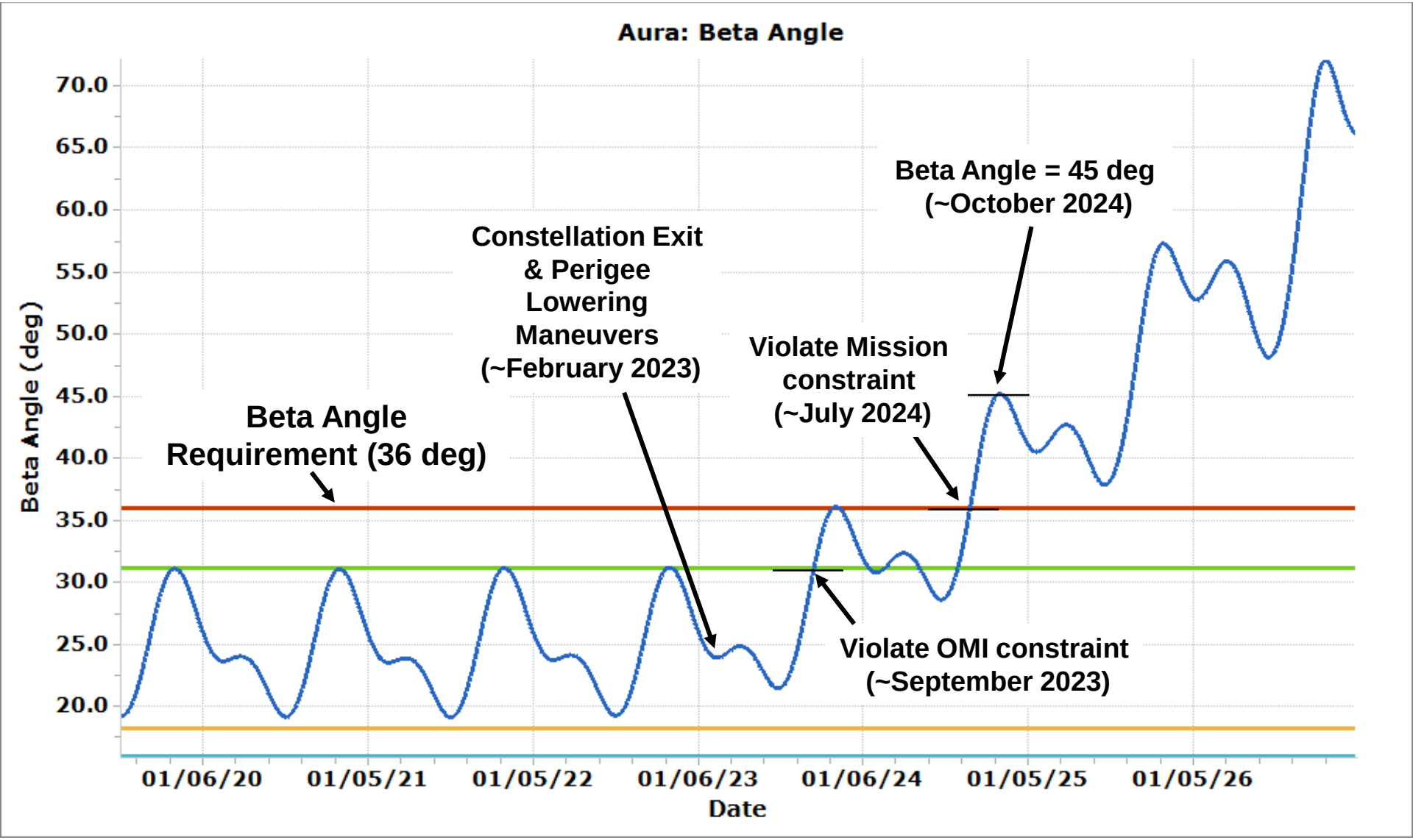
MLT Requirement: Constellation: 13:45 ± 15 min., Phasing with Aqua has kept MLT 13:38-13:50

Semi-Major Axis (SMA) Lowering



Semi-Major Axis: Constellation: 7077.7 km ± 0.3 km

Beta Angle Drift



Beta Angle Requirement: Mission: 16 deg. – 36 deg., OMI: 18.3 deg. – 31.2 deg.

Aura Future Power Generation

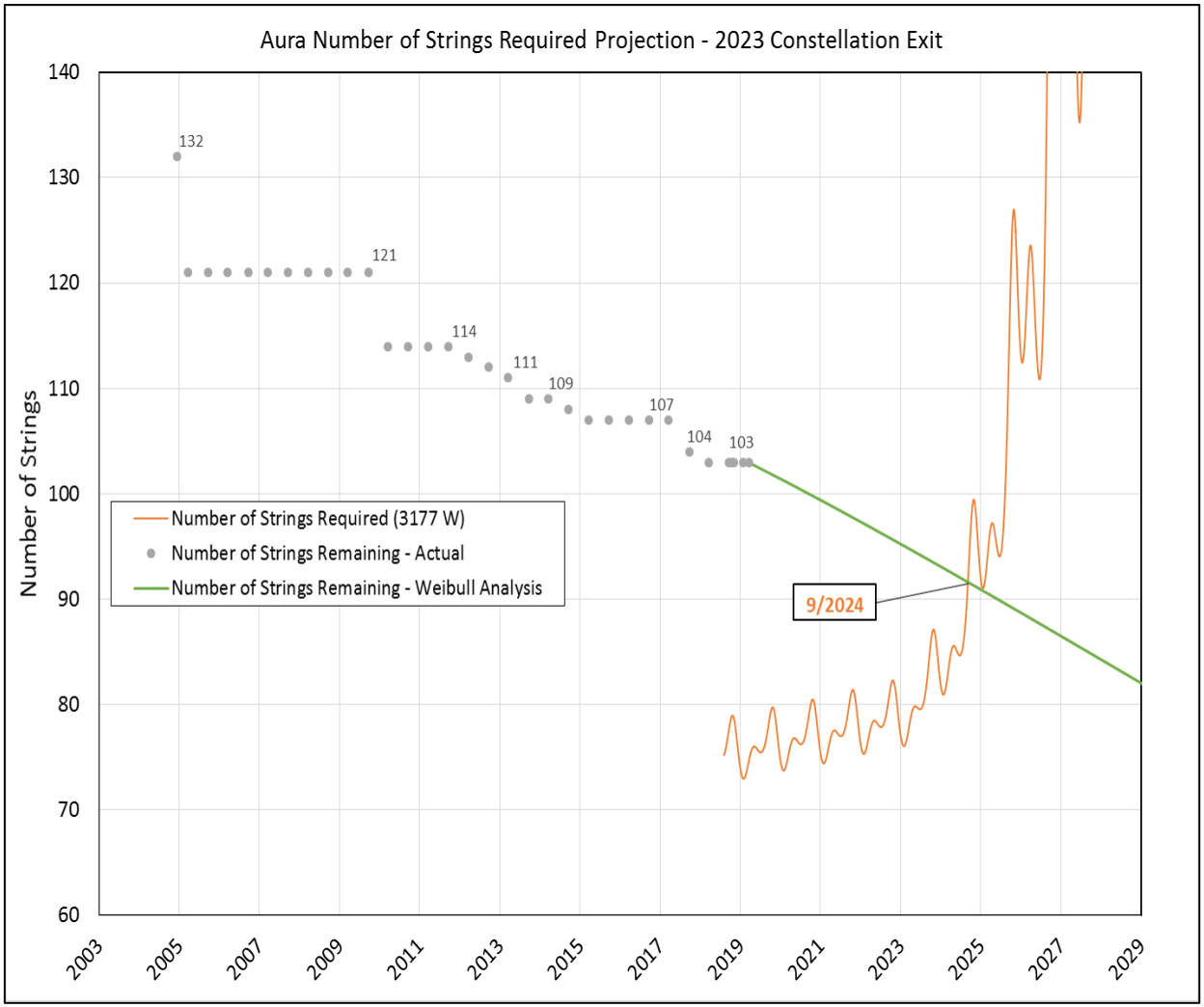
2023 A-Train Exit – Power Margin

Current power margin analysis estimates the **Minimum Required Power for Loads and Battery Charging = 3177 W**

Current best estimates for the 2023 exit case predict the power margin threshold would be violated in approximately **September 2024**

The number of strings required depends on what power we want to achieve and the Power per String

The solar array strings remaining projection comes from the Code 371 Weibull Analysis (updated 3/15/2019)



Conclusions

- As far as saving fuel in order to extend mission life, there isn't a clear advantage to exiting the A-train early since the power generation concern has the potential to then be realized sooner (2023 vs. 2024)

- As far as operations, maintaining existing products and procedures for as long as possible allows for greater consistency and continuity while reducing the risk on the health and safety of the mission hardware

- From the spacecraft and instrument perspective, it is recommended to stay the course with the baseline fuel usage plan as it provides the best opportunity for collecting high quality data for the longest duration

Questions?

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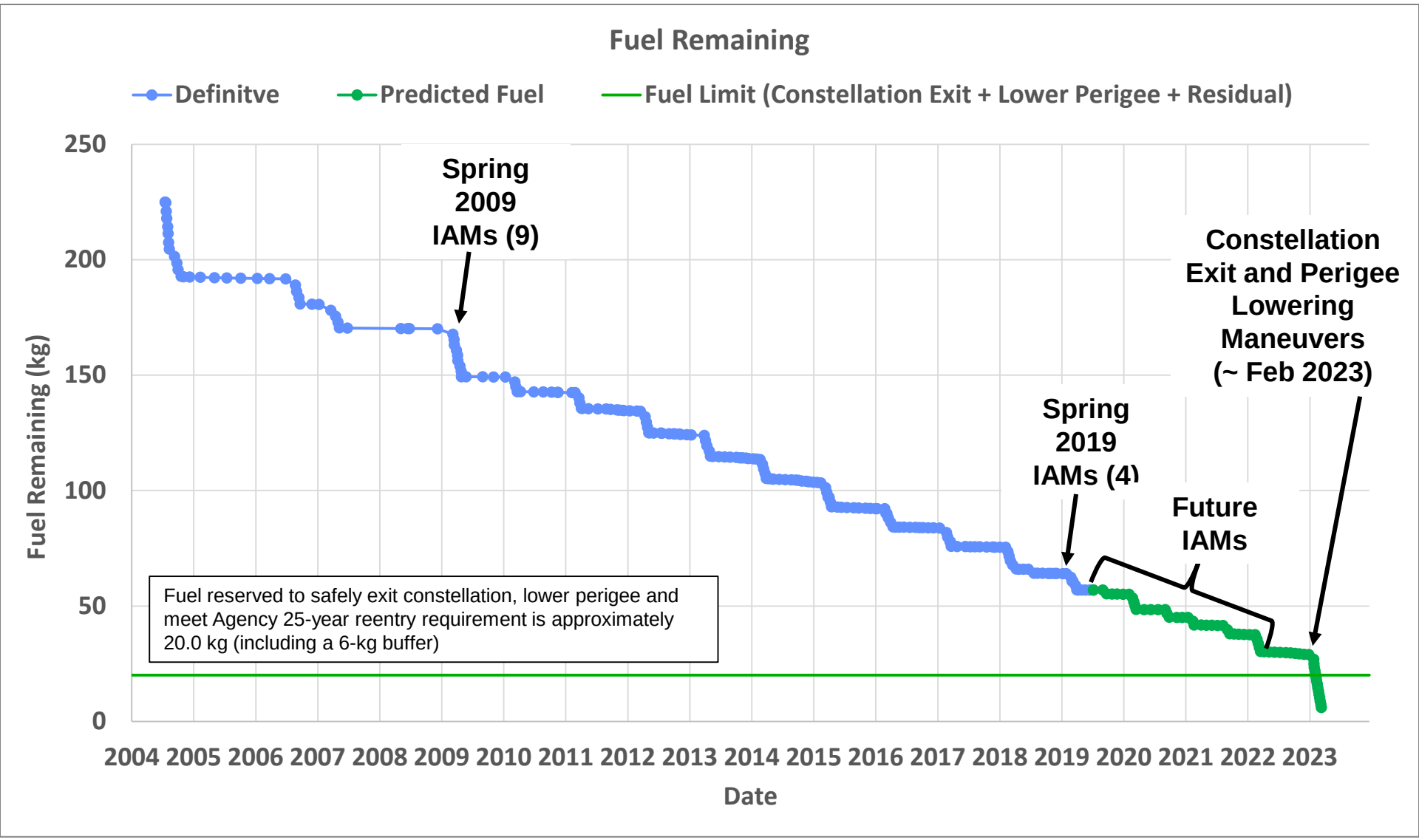
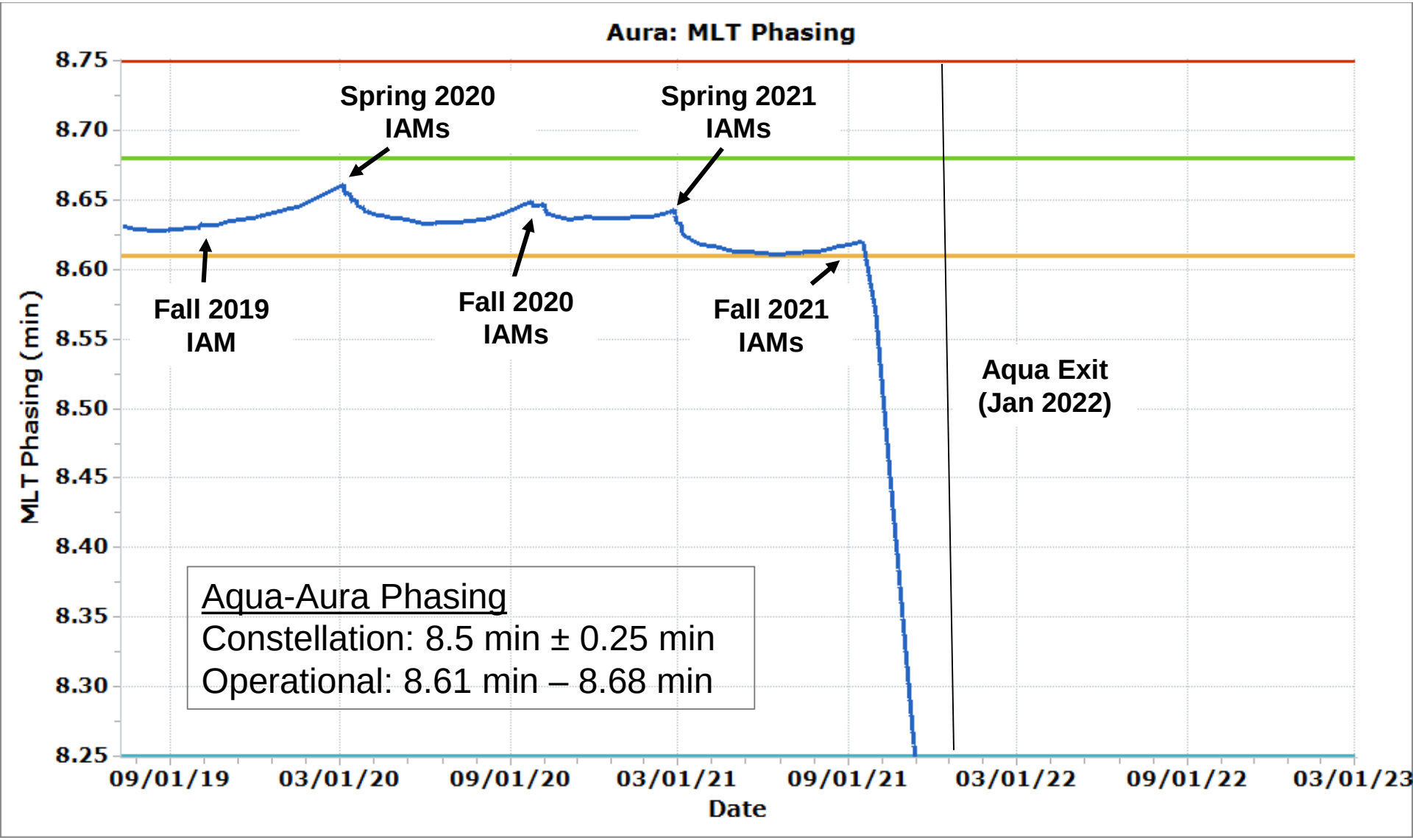
Timeline

- **January 2018 – Senior Review (2017) Guidance Letter Response included plans to assess implications of two potential measures to save fuel:**
  - Discontinue Inclination Adjust Maneuvers (IAMs) and exit the A-train early
  - Utilize the Reaction Wheel Assemblies (RWAs) to supplement thrusters during maneuvers → successfully executed in Spring 2019
- **09/11/2018 (De Bilt, Netherlands) – OMI Science Team Meeting**
  - Operations and science teams held splinter discussion about the implications of changing Aura's orbit (added to MOWG agenda)
- **11/08/2018 (@GSFC) – Aura Mission Ops & Science Team Quarterly**
  - Updated overall Aura Mission Status and Early A-Train Exit planning
- **12/06/2018 (@GSFC) – Earth Science Constellation (ESC) MOWG**
  - Presented Aura exit cases for comments by the A-Train member missions
- **06/03/2018 (@CNES) – Earth Science Constellation (ESC) MOWG**
  - Presented Aura exit cases and updated analysis for comments by the A-Train member missions
- **May/June 2019 – Updated Future Power Generation Analysis**
  - Concerns with power generation capability arise as the beta angle drifts after constellation exit

Fuel Remaining



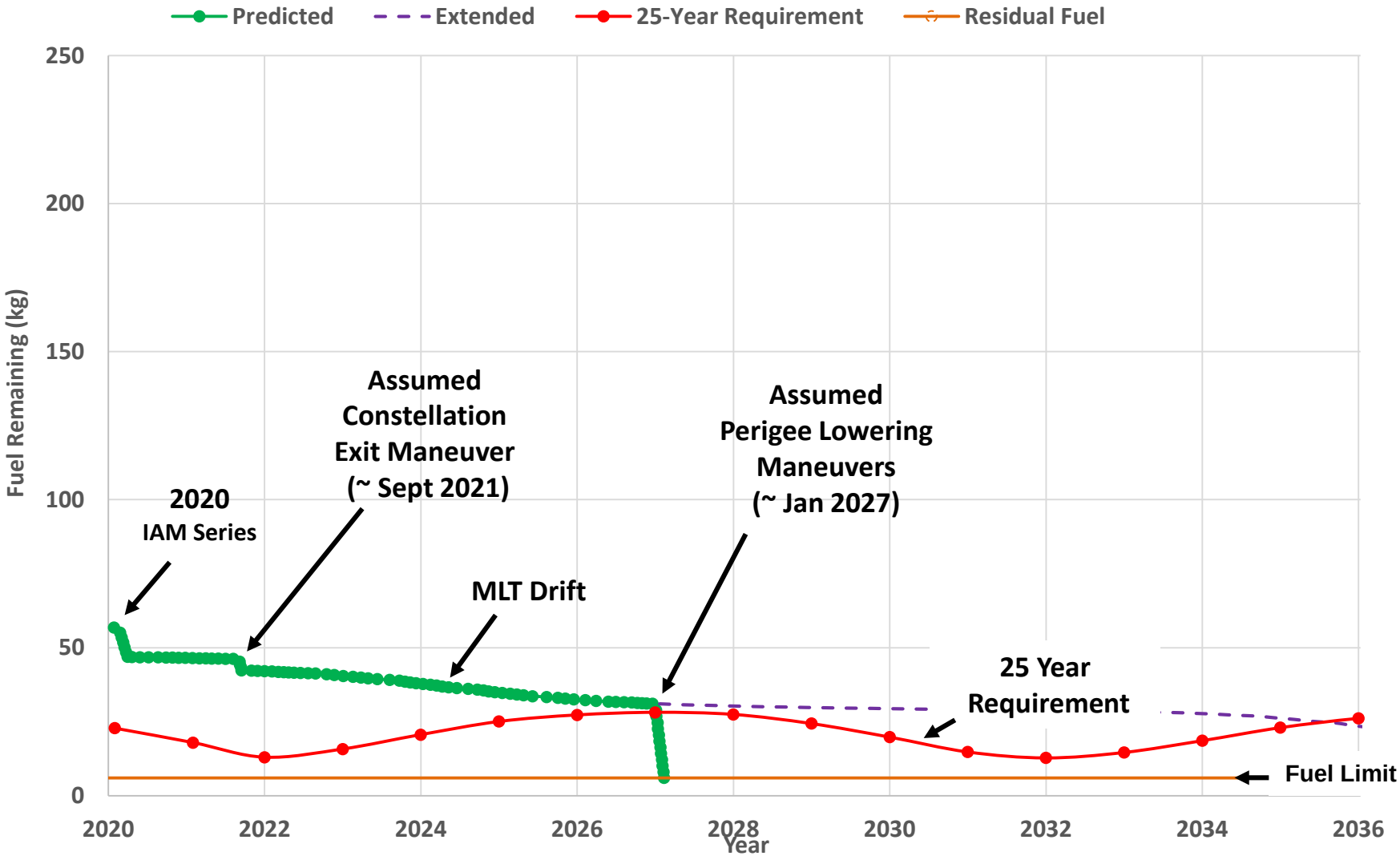
Aqua / Aura Phasing



Alternate Fuel Usage Case

Aura DAS End of Life Predictions

(Analysis Updated May 2019)



Aura Future Power Generation

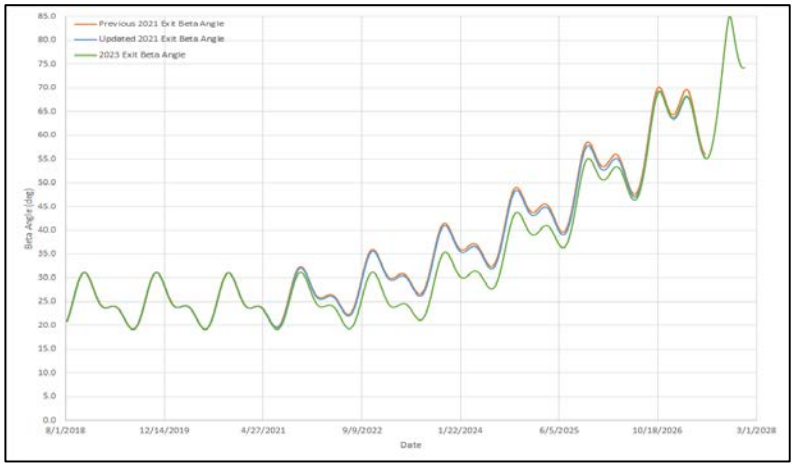
Aura Future Power Generation Analysis:

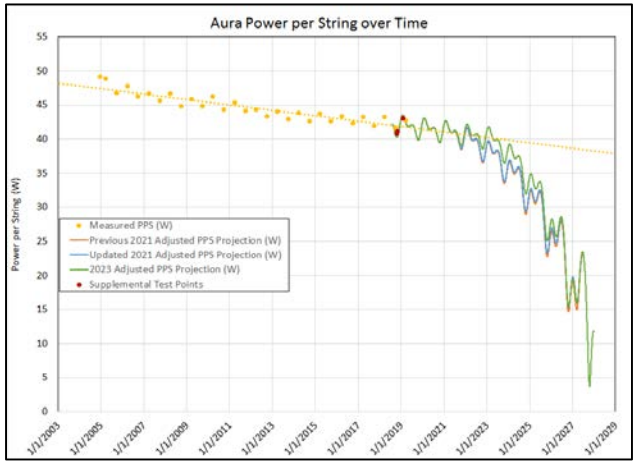
- **Working as part of the Electrical Power Subsystem (EPS) Power Working Group (PWG) with the Flight Ops Team (FOT), Northrop Grumman (NG), and Engineering & Technology Directorate (GSFC ETD)**
- **Determine how the Angle of Incidence (AOI) between the sun and the solar array affects the power that can be generated at given conditions**
- **Specifically, determine at what Angle of Incidence (AOI) the satellite is no longer able to generate enough power to sustain loads and charge batteries**
- **Analysis explores the two cases for the future orbit given the baseline or alternate fuel usage cases:**
  - Obtained Beta Angle predictions from Flight Dynamics System (FDS)
  - Obtained Earth-Sun Distance predictions from JPL's HORIZONS
  - Used Weibull Analysis to predict number of remaining solar strings
  - Used Previous Spring and Fall State-of-Health (SOH) Test data to predict how the Power-per-String (PPS) will degrade
- **Analysis updated in June 2019**

Aura Future Power Generation

Method:

- **Determine the Incident Sunlight Intensity Factor (ISIF) for each day given the Beta Angle and Earth-Sun Distance**
  - $ISIF = cos(Beta\ Angle) \cdot \frac{1}{(Earth{-}Sun\ Distance)^2}$
- **Adjust the Power per String (PPS) Projection to account for different ISIFs**
- **Determine Minimum Strings Required Projection based on the Adjusted PPS projection**
- **Determine when the Strings Remaining Projection drops below the Minimum Strings Required Projection**





Aura Future Power Generation Analysis

2021 Constellation Exit – Power Margin

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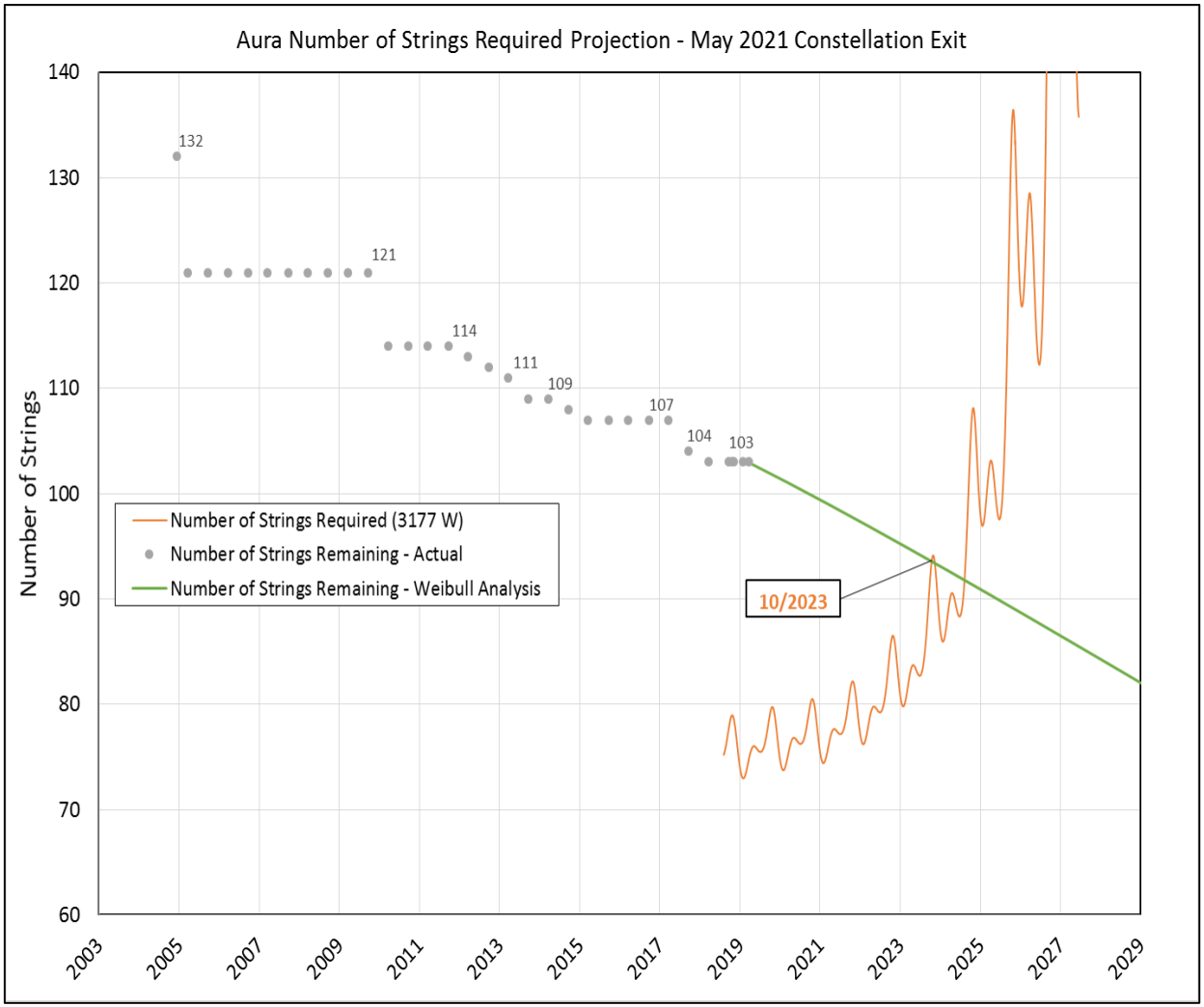

Case Comparison

Alternate Fuel Usage Case (2021 Constellation Exit)	Baseline Fuel Usage Case (2023 Constellation Exit)
- Science record at the 705 km A-Train orbit (17 years [2004-2021])	- Science record at the 705 km A-Train orbit (19 years [2004-2023])
- New science record to begin in 2021 after constellation exit (4.4 km lower)	- New science record to begin in 2023 after constellation exit and perigee lowering (new orbit 650 – 695 km)
- Conserve fuel by eliminating IAMs which allows for more fuel in reserve to re-enter <25 years	- Reach fuel limit in 2023 which drives need for constellation exit and perigee lower maneuvers to meet 25-year re-entry
- Power generation concerns begin around late-2023	- Power generation concerns begin around late-2024
- As the beta-angle and MLT drift, new instrument products and calibrations will be necessary (starting in 2021)	- As the beta-angle and MLT drift, new instrument products and calibrations will be necessary (starting in 2023)

Abbreviations / Acronyms List

AOI –	Angle of Incidence
ARE –	Array Regulator Electronics
ASAT –	Anti-satellite Weapon
CA –	Conjunction Assessment
CALIPSO –	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CARA –	Conjunction Assessment Risk Analysis
CDH –	Command & Data Handling
CEM –	Constellation Exit Maneuver
CNES –	Centre National d'Etudes Spatiales
COMM –	Communications
CONOPS –	Concept of Operations
COTS –	Commercial-Off-The-Shelf
CRMS –	Collision Risk Management System
DAM –	Debris Avoidance Maneuver
DAS –	Debris Assessment Software
DMUM –	Drag Make-up Maneuver
EA –	EOS Automation
EDOS –	EOS Data Operations System
EO-1 –	Earth Observing-1
EOC –	EOS Operations Center
EOL –	End of Life
EOMP –	End of Mission Plan
EOS –	Earth Observing System
EPR –	Engineering Peer Review
EPS –	Electrical Power System
ESC –	Earth Science Constellation
ESMO –	Earth Science Mission Operations
ETD –	Engineering & Technology Directorate
FDS –	Flight Dynamics System
FMU –	Formatter Multiplexer Unit
FOT –	Flight Operations Team
FSW –	Flight Software
GHz –	Gigahertz
GME –	Gigahertz Mirror Electronics
GMT –	Greenwich Mean Time
GNC –	Guidance Navigation & Control
GPM –	Global Precipitation Measurement
GSFC –	Goddard Space Flight Center
GTE –	Ground Track Error
HIE –	High Interest Event
HIRDLS –	High Resolution Dynamics Limb Sounder
HK –	Housekeeping
HQ –	Headquarters
IAM –	Interface Adapter Module
IAM –	Inclination Adjustment Maneuver
IOT –	Instrument Operations Team
JPL –	Jet Propulsion Lab
kg –	kilogram
km –	kilometer
L0 –	Level-Zero
LS –	Landsat
m –	meters
MLS –	Microwave Limb Sounder
MLT –	Mean Local Time
MLTAN –	MLT of the Ascending Node
MMOD –	Micrometeorite Orbital Debris
MOAR –	Mission Operations Annual Review
MOCA –	Mission Operations Conjunction Assessment
MOWG –	Mission Operations Working Group
MWG –	Maneuver Working Group
NASA –	National Aeronautics & Space Administration
NG –	Northrop Grumman
NYS –	No Yaw Slew
Ops –	Operations
OMI –	Ozone Monitoring Instrument
ORR –	Operational Readiness Review
Pc –	Probability of Collision
PLM –	Perigee Lowering Maneuver
PROP –	Propulsion
PWG –	Power Working Group
RCCA –	Root Cause and Corrective Action
RFA –	Request for Action
RMM –	Risk Mitigation Maneuver
RWA –	Reaction Wheel Assembly
SAA –	South Atlantic Anomaly
S/C –	Spacecraft
SMA –	Semi-Major Axis
SOH –	State of Health
SORCE –	Solar Radiation and Climate Experiment
SSR –	Solid State Recorder
TBC –	To Be Confirmed
TCS –	Thermal Control System
TES –	Tropospheric Emissions Spectrometer
TM –	Test Maneuver
TMON –	Telemetry Monitor
TROPOMI –	Troposphere Measuring Instrument
TRR –	Test Readiness Review
W –	watts
WG –	Working Group
WRS –	World Reference System